

OVERVIEW OF GRC'S ADVANCED SENSOR AND INSTRUMENTATION DEVELOPMENT

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Overview of GRC's Advanced Sensor and Instrumentation Development

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Overview

Glenn Research Center develops advanced diagnostic techniques to measure surface and flow properties in research facilities.

We support a variety of aerospace propulsion applications: Shuttle, X-33, X-43, ISS, and research engine components: inlets, compressors, combustors, nozzles.

We are developing a suite of instrumentation specifically for 3rd Generation Reusable Launch Vehicle testing.

Today's presentation:

- Overview
 - 3rd Generation Technologies
 - Additional flow and surface measurement technologies
 - Summary
-



3rd Gen Instrumentation Objectives

GOALS

- Increase safety by understanding operating conditions and component capabilities
- Reduce development and operating costs by:
 - Reducing testing and design cycle times and
 - Reducing engine weight and increasing component life

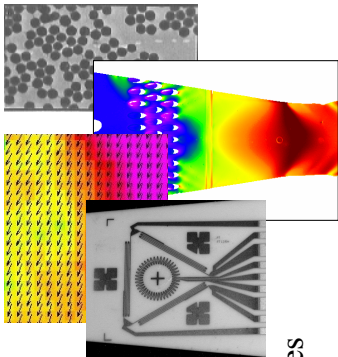
OBJECTIVES

- Determine cooling system effectiveness
- Determine structural loads

TECHNICAL CHALLENGES

- 2000 deg F surfaces; 8000 deg F flows; up to Mach 11
 - Remote signal extraction
 - Ultra-low intrusive measurements
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Technologies selected
to address objectives



Objectives

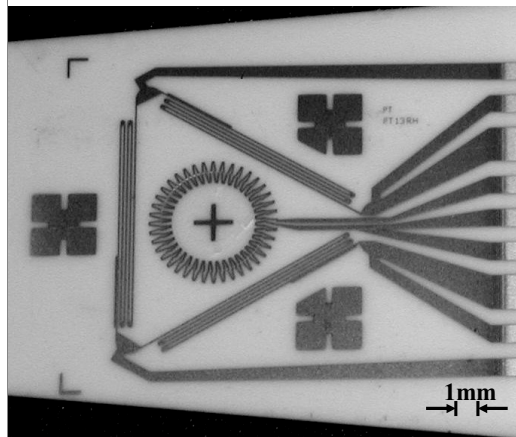
Technologies

	Thin Films/MEMS	Phosphor Paints	Velocimetry
Cooling System			
Surface Temp	●	●	
Surface Heat Flux	●		
Gas Temp			
Combustion	●		
Weight			
Surface strain	●		
CFD validation			
Velocity			●
Temperature	●	●	

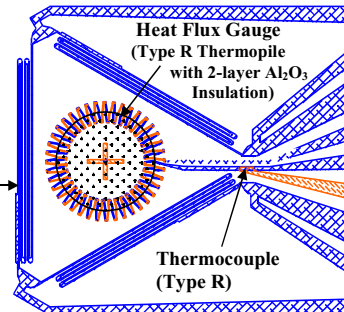
Thin Film Multifunction Sensor for Harsh Environments



- Strain Magnitude & Direction
- Flow Velocity and Direction
- Heat Flux & Temperature to at least 1100'
- Minimally Intrusive MEMS Design



Equilateral
Triangle
Strain
Gauge
(Pt or PdCr)



- Testing in bench-top environment
- Future testing on engine component & in relevant environment (⇒ TRL 4-5)
- “Smart” electronics package and attachable coupon version planned

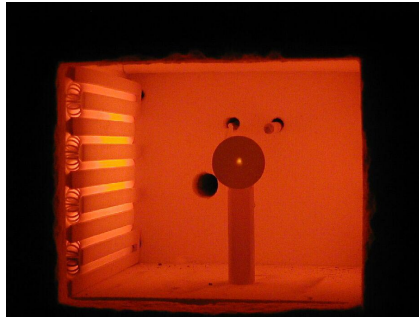
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High-temperature MEMS sensors to measure temperature, strain, vibration and heat flux, integrated into a single array.

Thermographic Phosphors for Surface Temperature and Heat Flux Measurements

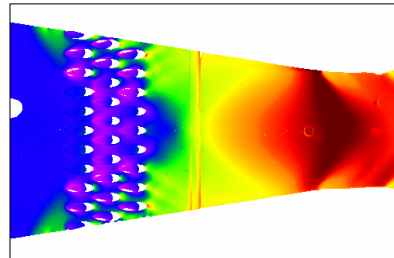


Paint surfaces using temperature sensitive paint
1000C operation demonstrated; new target is 1600C
Borescope inspection – no wires
Optically measure 2D heat transfer using paints survivable to 1000C



Phosphor temperature-indicating
emission at about 700 C

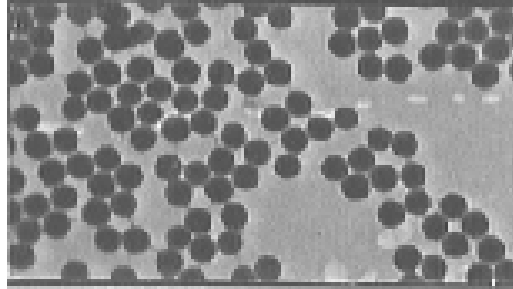
Optical data acquisition for
minimally intrusive full-surface data



Thermographic phosphors for gas temperature measurements



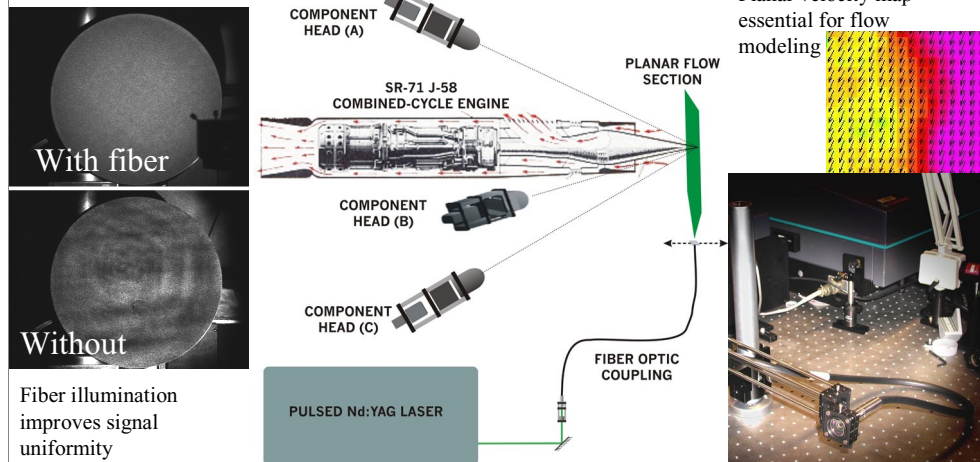
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- Continuously measure gas temperature using small seed particles entrained in the flow.
 - Planar gas temperature measurements – flow temperature profiling
 - Uniform nano particles fabricated for 250C operation
-



Multi-planar dynamic velocity measurements



- Develop unsteady, 3-component flow measurement compatible with the confined space encountered in advanced propulsion system inlets and flow paths.
- Fiber optic light delivery and collection minimizes optical access requirements
- MHz data capture at multiple planes for volumetric measurements



Additional Flow and Surface Measurement Technologies



In addition to our Space Transportation work, we are developing and using the following technologies as well:

Thin Films – surface strain, temperature, heat flux
Pressure sensitive paint – surface pressure
Particle imaging velocimetry – gas velocity
MEMS sensors – velocity, gas leak detection, pressure
Fiber optic Bragg sensors – strain, temperature, pressure
Spectroscopy - Combustion diagnostics
Rayleigh scattering – dynamic gas density, temperature, velocity
Schlieren – flow visualization, leak detection

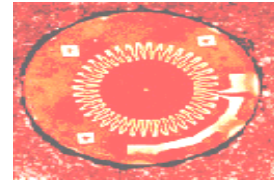


Thin Film Sensor Technology for minimally-intrusive,
high temperature strain, temperature, and heat flux measurements.

1995 & 1998 R&D 100 Award Winner



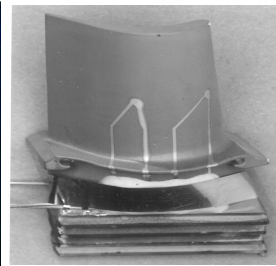
PdCr thin-film strain
gauge applied on Allied-
Signal Engines' ceramic
turbine blade.



Heat flux gage on
Silicon Nitride plug.



Thin film thermocouples
on ceramic matrix
composite hoop.



Thin film thermocouples on Space
Shuttle Main Engine turbine blades.

Very thin, minimally intrusive sensors provide high temperature data without disturbing flow.

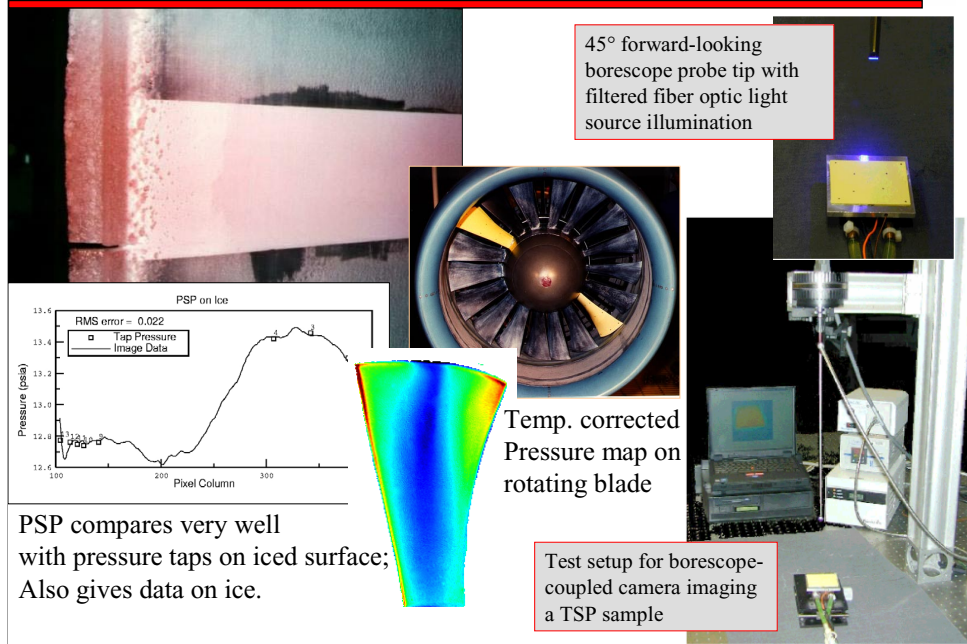
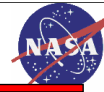
Fabricate directly onto ceramic and metal engine parts; no need to cut into the part.

Apply on metals, ceramics, and ceramic matrix composites.

Recent achievements:

- ◆ Received 1995 R&D 100 Award for thin film strain gauge
- ◆ Received 1998 R&D 100 Award for improved durability of wire connections to thin film gages
- ◆ PdCr strain gauge applied on Allied-Signal ceramic turbine blade
- ◆ Thermocouples applied to SSME turbine blades and CMC hoop
- ◆ Heat flux gauge applied on SiN plug
- ◆ High temperature survivability

Pressure Sensitive Paint on Ice, on Rotating machinery, and in confined spaces.



Reduce testing time by measuring pressure across entire surfaces rather than at discrete points in complex geometries including confined flow passages and ice accretions.

Recent Achievements:

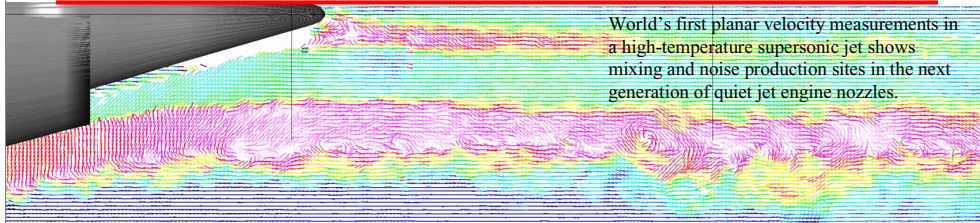
Full-view, high-speed rotating temperature and pressure measurements demonstrated on fan blades.

Application of PSP on ice accretions in IRT.

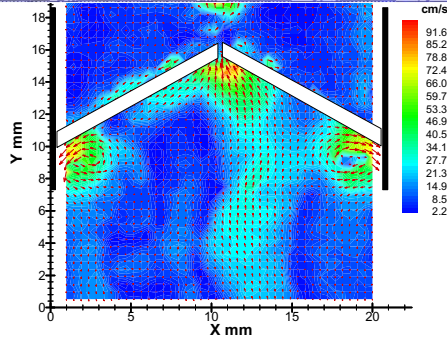
Developed 3D portable PSP system integrating multiple cameras/computers for multiple views, developing borescope system for windowless measurement.

Incorporated Temperature Sensitive Paint for temperature compensation.

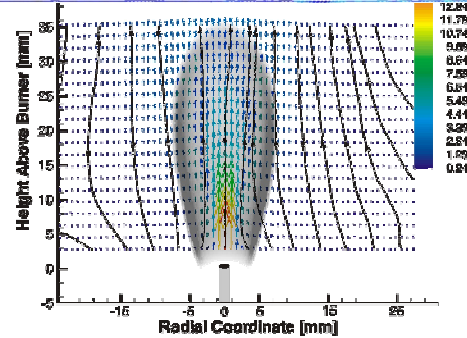
Generalized compensation algorithm



World's first planar velocity measurements in a high-temperature supersonic jet shows mixing and noise production sites in the next generation of quiet jet engine nozzles.



Detailed velocity measurements in an artificial heart valve, showing regions of stagnation potentially leading to blood clotting.

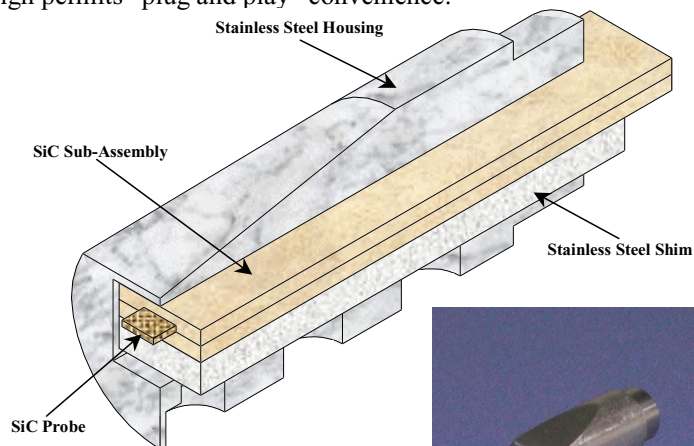


Planar velocity measurements in "microgravity" combustion flows. PIV system packaged for drop in the 2.2 second drop tower simulating weightlessness.

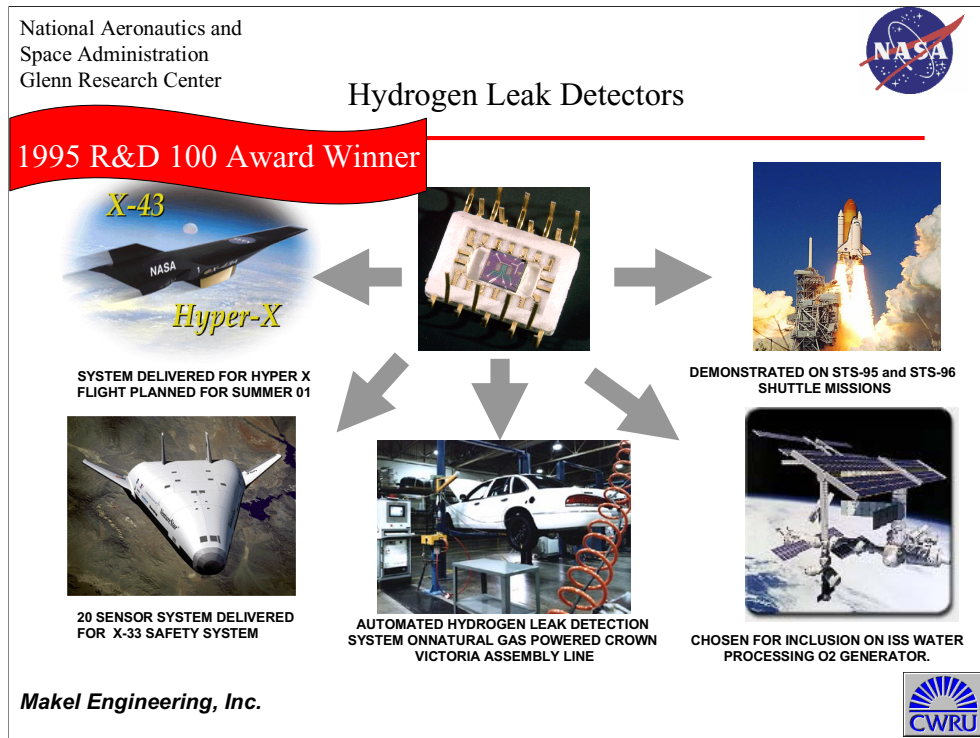


Turbulence Beam Probe

Silicon-Carbide fabrication enables velocity measurements at 600C.
Modular design permits “plug and play” convenience.



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Microfabricated using MEMS-based technology for minimal size, weight, and power consumption.

Highly sensitive in inert or O₂-bearing environments; wide concentration range detection.

Integrated with smart electronics for signal processing and temperature control.

Recent achievements:

- ◆ Demonstrated combined hydrogen and oxygen sensing integrated with electronics. Hydrocarbon sensor being developed.
- ◆ Flew on Space Shuttle STS-95 and STS-96 missions
- ◆ Selected for use on International Space Station
- ◆ 20 sensor system delivered to X-33
- ◆ Included on Chrysler's Crown Victoria assembly line



SiC-based Pressure Sensors

Excellent mechanical properties for use as a harsh environment sensor:
strong, large piezoresistive coefficients.

Form diaphragm of SiC and integrate with electronics.

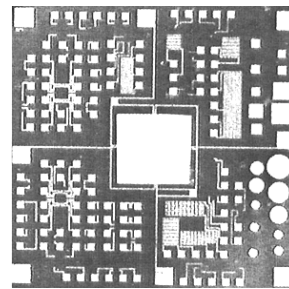
Micro-devices reduce size, weight and power consumption.

Integrated electronics and sensors provide “smart” solutions for harsh environments.

Recent achievements:

- ◆ Demonstrated operation at 500C in an engine
- ◆ Micromachining methods for harsh environment
 - ◆ MEMS developed

**SiC Pressure Sensor
with Electronics**





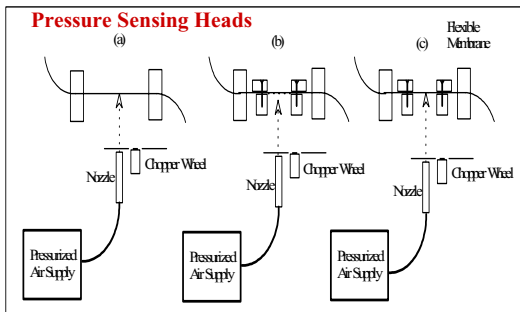
Fiber optic dynamic pressure detectors

Fiber optic Bragg gratings detect strain – relate to pressure based on mounting geometry.

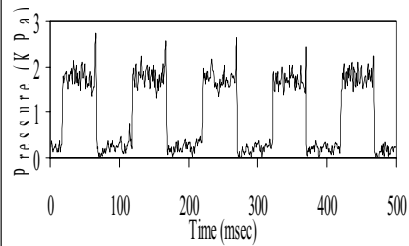
Interferometric spectrometer enables dynamic data readout – tracks pressure transducer well.

We've embedded these sensors into PMC plates, surviving up to 300C.

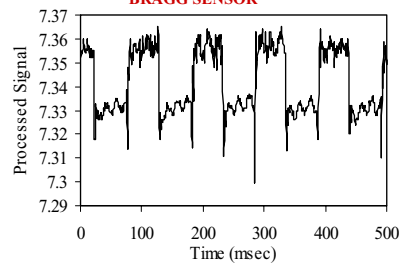
Pressure Sensing Heads



PRESSURE SENSOR

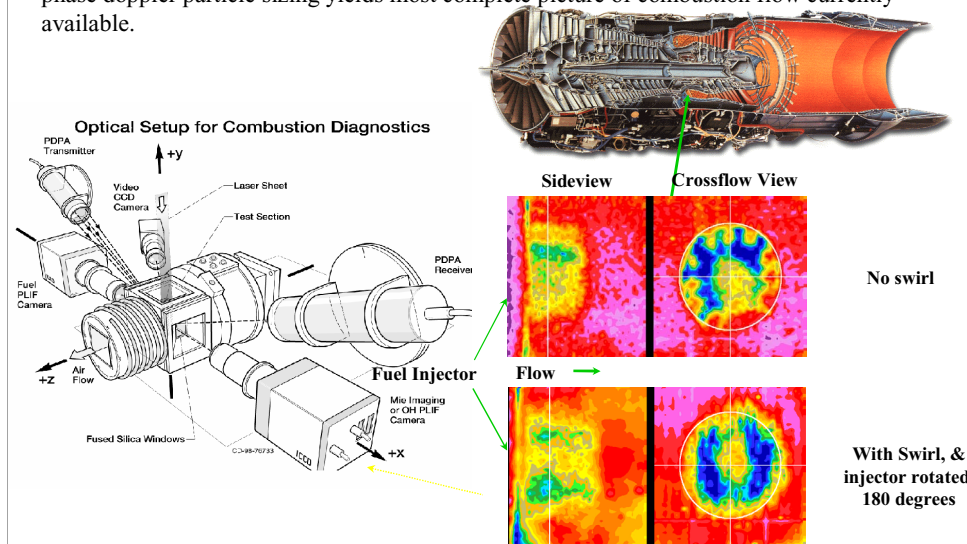


BRAGG SENSOR





Planar laser induced fluorescence and Mie scattering, chemiluminescent imaging, and phase doppler particle sizing yields most complete picture of combustion flow currently available.



Optical accessibility allows first ever direct visual observation of the effect of combustor configuration changes leading to informed next step alternatives in combustor and sub-component design modifications for improved performance and emissions reduction.

Mie data combined with PLIF data shows gas/liquid fuel distribution, may yield planar particle size distribution.

Planar data combined with PDPA yields most complete picture of combustion flow currently available.

Particle size distribution, spray angle, species distribution.

- ◆ Provide previously unavailable observations of combustor flows.
- ◆ Get data to understand effect of design changes to reduce emissions.
- ◆ Support code validation.

Recent Achievements:

- Demonstrated integrated suite of measurements in high-pressure (42 atmospheres) jet-fueled combustors:

OH, NO, and fuel PLIF; Mie scattering; PDPA; chemi-luminescence.

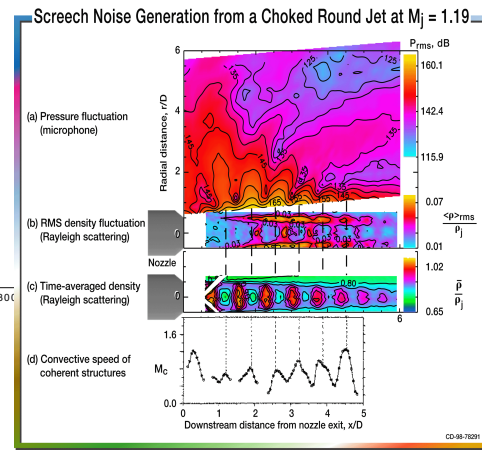
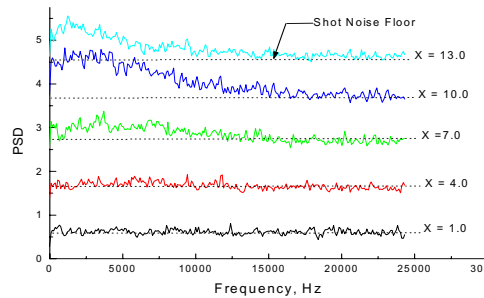
- Integrated PLIF and particle scattering measurements to quantify fuel-air ratio under certain conditions.
- Volumetric data processing permits virtual cross-flow views.



Dynamic Rayleigh Scattering

Optical technique to dynamically measure gas density, velocity and temperature.

Density power spectra measurements in a
supersonic free jet.



Point Rayleigh measurements scanned through out supersonic nozzle flow to measure time average density and density fluctuations.

Rayleigh data correlates to microphone noise measurements.

- ◆ Provide previously unavailable real-time data by making time-resolved density and velocity measurements in a free-jet
- ◆ Get data to understand physics of noise generation
- ◆ Support Unsteady NPARC Validation Experiment

Recent Achievements:

- Demonstrated simultaneous density, velocity, and temperature measurements in supersonic nozzle flow.
- Made first density measurements showing growth and decay of turbulent fluctuations in a supersonic free jet.
- Added fiber optic delivery system for use in high-noise environment.

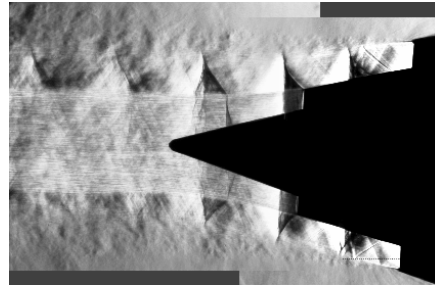


Focused Schlieren

-
- ◆ Ability to focus on a particular plane.
 - ◆ Get data to understand effect of design changes for noise reduction.
 - ◆ Real time test validation.
-

Recent Achievements:

- Added digital data acquisition, enabling post-test image processing





Summary

Advanced Instrumentation Development for Aerospace Propulsion Test Facilities

- Reduce project risk and vehicle/engine weight by using measurements to narrow uncertainty in operating and capability ranges.
- Reduce design cycle times by extracting maximum information from minimum testing
 - Characterize operating and capability ranges
 - Understand physics
 - Improve models
- Use advanced optical and MEMS technology to make measurements faster, more reliably, or where never before possible.
- Use integrated sensors/electronics and advanced data processing to extract maximum information.